8th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 19–23, 2000

The influence of Bi doping of the InAs/GaAs quantum dots on morphology and photoelectronic properties of the heterostructures obtained by MOVPE

B. N. Zvonkov§, I. A. Karpovich†, *N. V. Baidus*§, D. O. Filatov‡, S. V. Morozov† and Yu. Yu. Gushina‡

† University of Nizhni Novgorod, 603600 Nizhni Novgorod, Russia
‡ Research and Educational Center for Scanning Probe Microscopy, University of Nizhni Novgorod, 603600 Nizhni Novgorod, Russia
§ Physical-Technical Research Institute, University of Nizhni Novgorod, 603600 Nizhni Novgorod, Russia

Abstract. Bi doping of InAs quantum dots layer during growth by MOVPE depresses coalescence of nanoclusters and advances obtaining more uniform distribution of quantum dots size. Bi itself is practically not being incorporated into the QD material. Its role consists in limitation of In and As atoms diffusion mobility on the growing layer surface.

Introduction

One of the serious problems in growing the self-assembled quantum dot structures (QDSs) by MOVPE is to avoid coalescence of nanoclusters usually occurring at the growth temperatures which are optimal for their optical properties. Coalescence results in increasing of dispersion of the QDs in size, in decreasing their surface density and in formation of considerable number of relatively big clusters with continuous spectrum in QD layer [1]. We studied possibility of depressing the coalescence by Bi doping of QDs layer during growth. It was suggested that presence of bigger Bi atoms with less mobility on the growth surface will result in limitation of diffusion mobility of In and As atoms and to depress the coalescence.

Experimental

The GaAs/InAs QDSs were grown on (100) GaAs semi-insulating substrate with misorientation 3° towards [110] by atmospheric pressure MOVPE. The n-GaAs buffer layer was grown at 600°C. Then temperature has been decreased down to 530°C, then InAs QD layer was deposited. Trimethylindium and arsine were introduced into the reactor alternatively for 6 and 4 sec. respectively with the 4 sec. intervals between the cycles. Total number of the cycles was 10, the estimated InAs layer thickness was 1.5 nm (about 5 monolayers (ML)). Bi doping was made during the QD layer deposition by sputtering of the Bi target placed in the cold reactor zone (~12 cm away from substrate) by a Q-switch YAG pulsed laser. The estimated surface density of Bi is $\sim 10^{14}$ cm^{-2}. A number of structures both with and without 15 nm GaAs cap layer for optical and morphological investigations respectively were grown. Morphology of the QD layers was investigated by Atomic Force Microscopy (AFM) using TopoMetrix "Accurex" TMX-2100 AFM in contact mode. Also photoluminescence (PL) at 77 K and capacitive photovoltage (CPV) spectra at 300 K were measured.

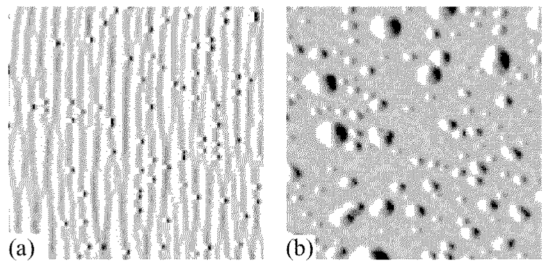

Fig. 1. AFM image of doped by Bi (a) and of undoped (b) InAs/GaAs quantum dots.

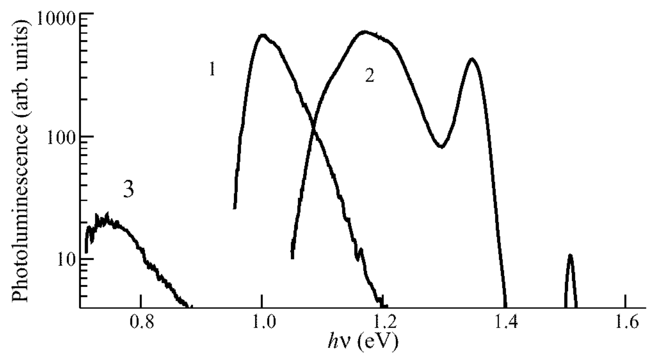

Fig. 2. The photoluminescence spectra of QDS doped by Bi (77 K). 1 and 2 — QDS with GaAs cap layer for different Bi doping regime, 3 — QDS without cap layer.

Results and discussions

The Bi doping of the QD layer during growth suppresses coalescence. It is especially clear if In concentration in the InAs layer is not too much.

Figure 1 shows the surface topography of the QD layer without GaAs cap layer with (a) and without (b) Bi doping. The other growth parameters were the same. In the first case the dots are highly uniform in lateral size (41 ± 2 nm) as well as in height (5.8 ± 0.2 nm). Although there is almost no big clusters the surface density of QDs was rather low (4×10^9 cm^{-2}). Increasing the In concentration in the QD layer increases QD density, but efficiency of coalescence suppression becomes less at the same concentration of Bi. Possibly optimization of In and Bi flows will allow to increase QD surface density without surface morphology degradation.

The PL spectra of the undoped QDS have FWHM about 60 meV at 77 K. The Bi doped QDS have more narrow peaks with FWHM 40 meV (Fig. 2, curve 1) as well as the abnormal broad ones with width up to 200 and even 300 meV (curve 2). Appearance of the ones can be ascribed to fluctuations of Bi surface concentration and therefore to fluctuations in QD size in certain growth regimes. The lowest peak energy $h\nu_m \approx 1.0$ eV at 77 K has been observed. This value fits into the 1.3 μm band important for optronics applications. Such a position of a PL peak cannot be ascribed to presence of Bi in the QD material, because the QDs grown without Bi doping also show PL in this band [2]. Because of big covalent radius Bi atoms are likely to be hustled away to the growth surface or to InAs/GaAs interface. Therefore, another mechanism of Bi influence on self-assembled growth of the QD array, namely due to changing of the surface energy [3] should be proposed.

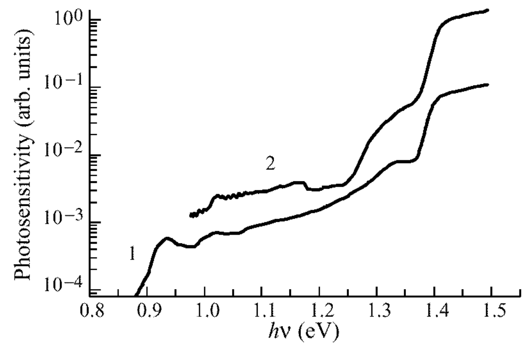

Fig. 3. The photosensitivity spectra of QDS doped by Bi (300 K).

On the doped QDS without cap layer as low values of $h\nu_m \approx 0.75$ eV (Fig. 2, curve 3) at 77 K have been observed for all samples. The correspondent ground transition energy at 300 K is ≈ 0.67 eV. Shift of the PL maximum for structures with surface QDs can be explained by partial elastic strain relaxation in the QD [4].

Usually photoelectric sensitivity of the QDs at 300 K can be observed only in the QDS with thin GaAs covering layer ($\sim$15 nm) so that the QD layer is built in the depleted region of the surface barrier. The strong electric field favor emission of the electron-hole pairs from the QDs. But if the QD layer is situated on the surface, photoluminescence and photosensitivity can be observed only if the QD density is high ($\sim 10^{10}$ cm^{-2}) due to a high surface recombination rate.

CPV spectra of the QDS are shown in Fig. 3. Photosensitivity threshold corresponds to PL peak position (Fig. 2) taking into account the thermal band gap shift $\approx$80 meV. The ground transition and thin structure at high energies due to transitions to higher excitation levels are well resolved.

Conclusions

In conclusion, the results of this work show that Bi doping of InAs QDs is an effective tool for improving the morphology and photoelectric properties of the QDS obtained by MOVPE.

Acknowledgements

This work was supported by the RFBR (98-02-16688), by the Program "Physics of Solid-State Nanostructures" (grant 99-1141), by Russian Ministry of Education (97-7.1-204), by "Universities of Russia" Program, and by BRHE Program (REC-001).

References

[1] N. V. Baidus, B. N. Zvonkov, D. O. Filatov, J. J. Gushina, I. A. Karpovich and A. V. Zdoroveyschev, *Proc. Russian Workshop 'Probe Microscopy-99'* (Nizhnii Novgorod 1999), p. 164.; *Poverkhnost* 2000 (in press) (*in Russian*).

[2] I. A. Karpovich, D. O. Filatov, S. V. Morozov, N. V. Baidus, B. N. Zvonkov and J. J. Gushina, *Izv. Akad. Nauk, Ser. Fiz.* **63**, 331 (2000) (*in Russian*).

[3] V. A. Shchukin, A. I. Borovkov, N. N. Ledentsov, P. S. Kop'ev, M. Grundman and D. Bimberg, *Phys. Lov-Dim. Struct.* **12**, 43 (1995).

[4] H. Saito, K. Nishi and S. Sugou, *Appl. Phys. Lett.* **73**, 2742 (1998).